Mesoscale Processes in Tropical Cyclones

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LONG-TERM GOALS

I have four long-term goals. My first goal is to finalize the large body of work already carried out by the PI on the predictability of tropical cyclone (TC) forecast *tracks* out to 72 hours ahead. My second goal is to apply similar, as well as new, ideas to the predictability of forecast *intensity* out to 72 hours ahead. My third goal is to carry out observing system simulation experiments (OSSEs) on the Aerosonde data. Finally, my fourth goal was to commence work on applying adjoint sensitivity and other techniques to increase our understanding and predictive skill of TC intensity and precipitation, especially TCs nearing and making landfall. The above goals all have implications for transitions.

OBJECTIVES

My first two scientific objectives are, respectively, to estimate the so-called intrinsic limits of predictability of tropical cyclone mean forecast position errors and of tropical cyclone intensity errors.. Intrinsic limits of predictability for TCs exist because the equations governing the behavior of all atmospheric systems, including TCs, are deterministically chaotic. As such, any errors in the initial conditions, model formulation and boundary conditions lead to error growth that eventually swamps the skill of the forecasts and they become worthless, at least at face value. In the *first objective*, namely TC track forecast errors, I have compared these intrinsic limits with the results that are currently being obtained in practice with state-of-the-art real-time NWP models. The objective is to see how close we are, in practice, to what is our best estimate of what is possible in theory. The *second objective* is the equally important need to obtain estimates of the predictability of TC intensity, and how large the gap is between that being obtained in practice and the ultimately achievable. Work has only just commenced on this objective. The *third research objective* was to assess the impact of Aerosonde data on both TC track and intensity predictions. My *fourth and final objective* is new research work on improving understanding and forecasting skill for TC intensity and intensity change, especially when approaching landfall.

APPROACH

My approach for each of the four goals is as follows. The methodology employed for the first goal has been explained fully already in the ONR FY99 report and in the literature (see, eg Leslie and Abbey, 2000). This work has involved the use of two very distinct techniques that yield almost identical answers, thereby adding confidence to the findings. The first goal, as mentioned above, was to produce estimates of the lowest possible mean forecast track errors out to 72 hours and to determine how closely they are currently being approached in practical numerical weather prediction (NWP)

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14. ABSTRACT

I have four long-term goals. My first goal is to finalize the large body of work already carried out by the PI on the predictability of tropical cyclone (TC) forecast tracks out to 72 hours ahead. My second goal is to apply similar, as well as new, ideas to the predictability of forecast intensity out to 72 hours ahead. My third goal is to carry out observing system simulation experiments (OSSEs) on the Aerosonde data. Finally, my fourth goal was to commence work on applying adjoint sensitivity and other techniques to increase our understanding and predictive skill of TC intensity and precipitation especially TCs nearing and making landfall. The above goals all have implications for transitions.

15. SUBJECT TERMS

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models. The practical limits have been improving steadily as the sustained effort in TC track forecast continues at centers around the world. The NWP model I have been using the model was developed at UNSW and is referred to as HIRES. My approach has been to generate an ensemble of initial model states using a modified Monte Carlo technique to the archived data sets from various operational global NWP centers around the world (Australian Bureau of Meteorology, UKMO and NCEP). The initial fields generate corresponding ensembles of forecasts at 12 hourly intervals out to 72 hours, after re-setting the TC positions back to their best track locations every 12 hours (Abbey et al., 1999). The alternative technique was to use a non-linear systems approach to the archived best track data sets in the manner described by Fraedrich and Leslie (1988). In this case, the spread of initially close pieces of TC trajectories is calculated over a 72 hour period for all available data sets. My second goal, which is one of the more difficult and significant problems facing TC research today, is to apply the procedures that proved to be successful in achieving the first goal to the new problem of estimating the predictability characteristics of TC intensity and intensity change. The task is a very large one and only the preliminary stages could be achieved in the present ONR funding cycle. Again, the goal is to calculate predictability limits and how close we are to those in practice. These limits will then be compared for the various TC basins and will again provide information about how close current operational models are to the limits of predictability. The third goal, which is now essentially completed, was to assess the impact of Aerosonde data using an OSSE. This work was carried out in collaboration with Dr Greg Holland and is a series of numerical experiments, the first being a very high resolution models run for a TC which is taken as the “true” state of the atmosphere. An extensive series of model runs using an initially degraded resolution but with 1, 5 and 9 Aerosondes deployed in various patterns was then carried out. This approach is a standard one that has proven to be highly effective in many other kinds of applications. My fourth goal was to obtain much more realistic TC intensification rates and precipitation patterns than have achieved hitherto. Before this work began, I had been producing steadily improving forecasts of TC tracks but had failed to capture the intensity and intensity changes of the TCs. This failure is of extreme importance for TCs at or nearing landfall. The procedure adopted was to use and adjoint sensitivity approach to identify the contributing factors to intensity change and the improvement in the forecasts themselves. In 2000, I have built upon a breakthrough achieved in 1999, by continuing to use four dimensional variational assimilation procedures without TC bogussing, taking advantage of high spatial-temporal frequency satellite derived data of various types and as many other sources of data as possible.

WORK COMPLETED

So far I have completed the first goal, commenced the second, completed the third and have preliminary results for the fourth goal. The completed first task calculated the difference between the mean absolute forecast track errors for tropical cyclones obtained in practice with estimates of what could be achieved in principle. The final findings have been published (Leslie and Abbey, 2000). My second goal of applying the same procedure to TC intensity predictability has reached approximately the halfway mark. No firm results have yet been obtained as the data collection and validation phase is a long and arduous one and must be completed if believable estimates are to be produced. Another part of the process, the further development of the HIRES data assimilation and prediction system has proceeded. There has been an expansion of the capacity of the system to ingest a large range of new data sources and continued success in obtaining realistic TC intensity forecasts and TC structure (eg, Leslie and LeMarshall, 2000; LeMarshall and Leslie, 2000). Figure 1 in the RESULTS section illustrates progress in both track and the data availability. My third goal of carrying out an OSSE using various deployments of the Aerosonde has been completed and the results show clearly that at least 5 Aerosondes are required to achieve a significant positive impact, but that beyond 5, there is diminishing returns. The viability of the Aerosonde data is illustrated in the Figure 2 of the RESULTS section, below. My fourth goal of understanding the contributing factors to, and improving the forecasts of TC intensity and intensity change, especially for landfalling TCs, has yielded early promising results. In this case, see Figure 3 and Table 1 of the RESULTS section.

RESULTS

I have now produced four main sets of results for FY00. The first set of results relates to the first goal, which was to determine how close current NWP models are to the best estimate of the limit of predictability for TCs. The chaotic nature of the systems and the governing equations results from the non-linearity of the system together with the multifarious feedback processes that take place in such complex systems. The FY00 results are now completed and are given in Leslie and Abbey (2000). The major finding of FY99 was confirmed, namely, that there is still a large gap of somewhere between 35 to 50% in what is being achieved at present and what is possible. This is a very large gap in that if the 50% difference is correct, the model forecast errors of TC track position can be *halved* in the future.

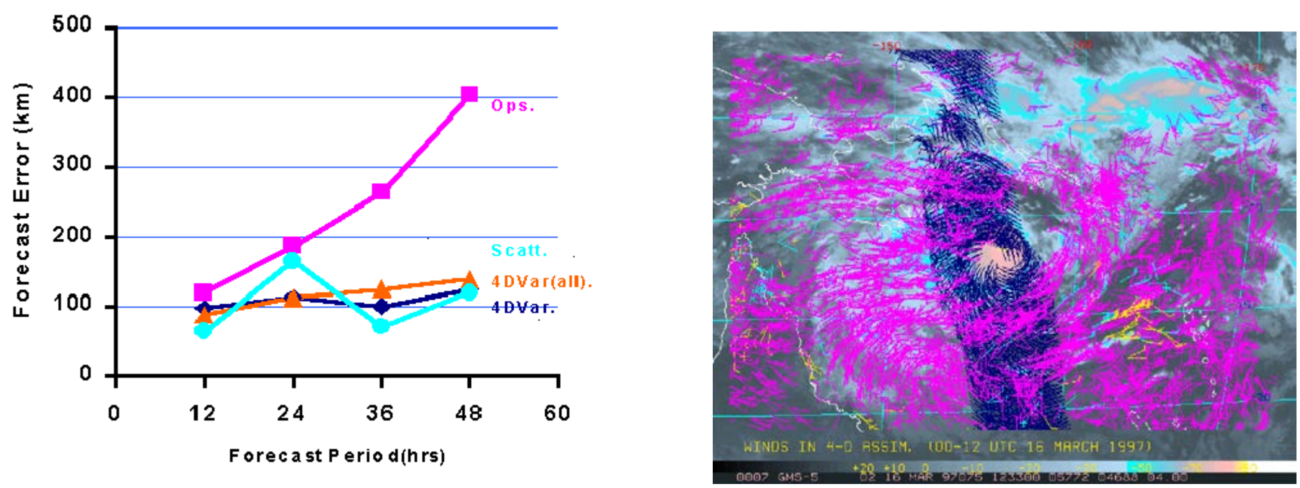

Figure 1: The figure on the left shows a comparison of TC track errors for 12 "difficult" tropical cyclones. Operational results are seen to be greatly improved by the use of high resolution 4-D data assimilation schemes which take advantage of the enormously enhanced data base typified in the figure on the right.

The left side of Figure 1 shows the potentially large further gains being made in TC track error reduction for a set of 12 difficult TCs. Much of the improvement has been a result of the massively improved data coverage as shown in the right figure. It is anticipated that considerable reductions will be obtained in TC track errors over the next few years as a result of continued improvements in data assimilation procedures, better data coverage and quality and improved model formulation and resolution. My work on the second goal has just commenced and the first results are just becoming available. I am estimating the inherent errors of TC intensity and intensity change using an approach similar to that in the first goal. I will then compare the results with the errors obtained from operational models. This task is more difficult than the first one, owing to the fact that intensity data is of poorer quality than track data. However, careful choice of TCs can greatly improve the quality of the data. Turning to the third goal. The results I have obtained thus far have proved to be very encouraging. One of the problems I have had in common with many other TC modelers was that although the track forecasts were improved steadily the intensity of the model generated TCs was far too low. Some success has been obtained by other researchers who use bogussing techniques to estimate of the initial location, intensity, size, asymmetry and speed and direction of movement of the TC vortex.   However the PI had shown in earlier work that there were major problems with the use of bogus techniques. By using a long period of numerical experiments with a range of resolutions, data assimilation techniques and model formulations and resolutions it was demonstrated (LeMarshall and Leslie, 1999, Leslie and LeMarshall, 2000) that realistic intensification of TCs could be obtained. Simply by using the standard methods of high temporal and spatial resolution data during assimilation, an effective initialization procedure, and very high resolution, greatly improved TC forecasts of track and intensity were produced. The results of this work have been referred to as “pioneering” by WMO and were reported on in the December 1999 meeting of the WMO COMPARE committee of which the PI is chair. The third goal was to carry out an OSSE to assess the impact of Aerosonde data on TC track and intensity errors. Figure 2, below, shows that there is a very significant impact and that there is a large improvement between 1 Aerosonde and 5 Aerosondes, but with diminishing for 9 Aerosondes.

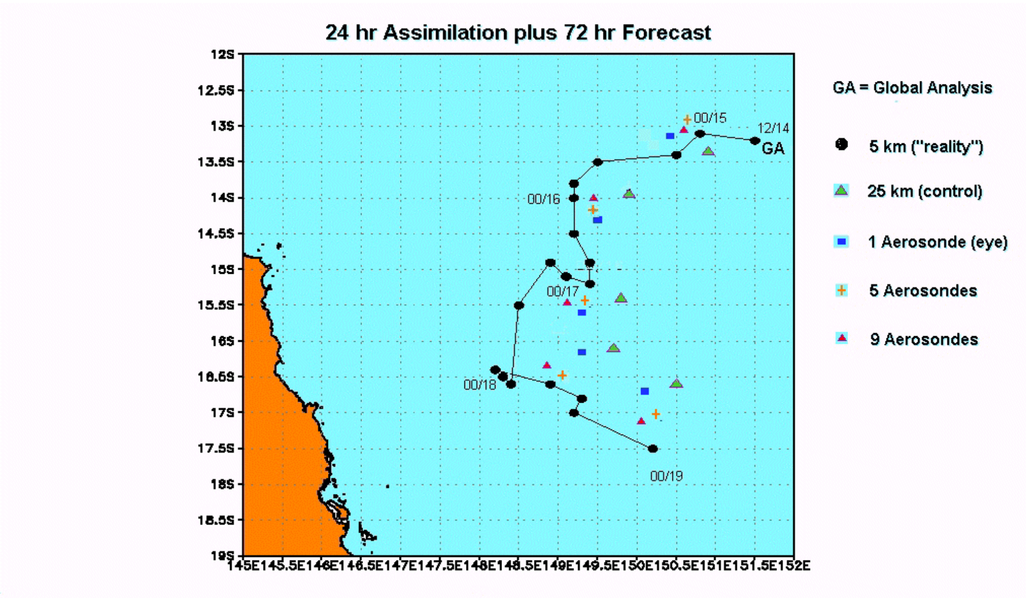

Figure 2: Schematic of the Aerosonde OSSE. Details are given in the text.

The OSSE was initialized with a global analysis and then a 5 km model forecast was performed and was defined to be the actual atmospheric state, or “reality”. A control run at 25km resolution was carried out using a degraded analysis grid and data stream. Finally, data was added from idealized soundings from 1, 5 and 9 Aerosondes was included and the new tracks computed and compared in Figure 2. The OSSE has now been completed. My fourth goal was to obtain much more realistic TC intensities and precipitation patterns than have achieved hitherto. Additionally, I have been using an adjoint sensitivity approach to identify the contributing factors to intensity change and in improving precipitation forecasts.   This year I have continued to use four dimensional variational assimilation procedures without TC bogussing, taking advantage of high spatial-temporal frequency satellite derived data of various types and as many other sources of data as possible. A necessary part of this approach is to run the NWP model at very high resolutions of 5km or less. Another contributing factor is the continued improved treatment of moist processes in the model. An example of the prediction of a landfalling TC is given in Figure 3 with the corresponding forecast and observed rainfall totals shown in Table 1. Five other category 5 TCs have been simulated and the results are currently being prepared for publication.

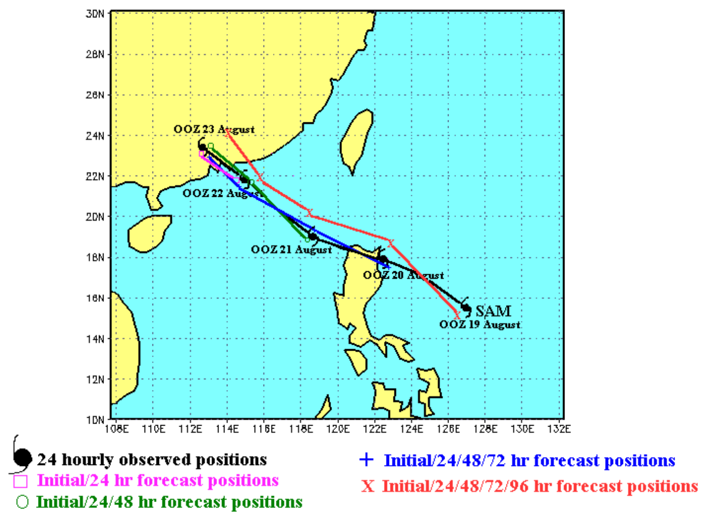

Figure 3: The TC tracks for Typhoon Sam in the northern West Pacific. The typhoon made landfall over Hong Kong and brought record 24 rainfall totals at the Hong Kong Observatory. Note the consistency in the 24, 48, 72 and 96 hour forecasts using the UNSW data assimilation and prediction systems.

Table 1: A comparison of observed and forecast rainfall totals at Hong Kong Observatory, for Typhoon Sam, at 1, 2 and 3 days ahead. These forecast rainfall results are very encouraging. Further work will be carried out on quantitative rainfall predictions for TCs making landfall, particularly, for TCs producing extreme rainfall totals over both short and long periods of time.

Aug. 1999	21st	22nd	23rd	Total Obs.	Total Fcst.
Observed	7	158	207	372	
Forecast	17	205	196		418
Observed	7	158	207	372	
Forecast	22	189	251		462
Observed		158	207	365	
Forecast		126	181		307
Observed			207	207	
Forecast			164		164

IMPACT/APPLICATIONS

My work has yielded a number of impacts/applications. First, I have shown that TC track forecast errors are still large in that there is approximately a 50% difference between the inherent errors and the errors in practice. The positive aspect of this result is that there is still room for progress and that progress is being made. A second impact I have confirmed from the FY99 report is that quality high resolution data from existing and new sources, developments in continuous (4D) assimilation and model improvements continue to achieve major reductions in track forecast errors, especially for “difficult” TCs. Third, I have confirmed tentative FY99 findings that realistic intensity forecasts and TC structure require resolutions of 10 km or less, preferably around 5km. It is now becoming routine to obtain TC simulations that have many of the observed features of actual TCs, a situation that was novel just a few years ago. This further confirms my conclusions of FY99 that the prediction of TC tracks and intensities is moving within the reach of the emerging data observing systems, advanced assimilation schemes and the more sophisticated NWP models running at very high resolutions. Fourth, the value of the Aerosonde data has been demonstrated in an OSSE that I carried out in FY00. Finally, new adjoint sensitivity techniques are yielding very promising results in understanding and predicting TC intensity , intensity change and precipitation amounts.

TRANSITIONS

Much of my work has potential for transition, not only in the TC forecasting area but more generally.

RELATED PROJECTS

I have continued my close links with other ONR programs, especially that of Dr Greg Holland in an OSSE aimed at assessing the impact of the Aerosonde data on TC track and intensity prediction.

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